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The Effects of Drying Conditions on the Properties of Fines

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THE EFFECTS OF DRYING CONDITIONS ON THE PROPERTIES OF FINES

by
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ABSTRACT

This project was designed to study the impact of drying on the properties of fiber fines. Three different drying conditions were used : force-dry (0% moisture), force-dry (6% moisture), and air-dry (6% moisture). Fines were evaluated in the paper and in the pulp both before and after recycling.

In order to study the impact of drying on the fines, fines were removed from the virgin furnish. Characteristics of the control stock containing fines and of the control stock without fines were evaluated and served as a means of comparison. Stocks were tested for wet-web strength, drainage, freeness, and water retention value. Two sets of handsheets (fines-free and fines-containing) were made at each condition. Handsheets were evaluated for brightness, opacity, scattering coefficient, absorption coefficient, density, and tensile index. Handsheets were then repulped and tests were performed, as before, on the stock. All recycled pulps were then used to prepare air-dry handsheets which were evaluated again for strength and optical properties.

Results show that force-dry (0% moist.) fines, both before and after recycling, contributed the most to density and tensile index because of lower fines-free values, but the least to wet web strength. Force-dried fines were less active than air-dried fines but more necessary because of this. Air-dried fines were more active and had the lowest scattering coefficient and CSF, and had the strongest wet-web and paper. Bonding potential was reduced in all cases by drying, as indicated by lower densities, tensile indexes, wet-web strengths, and water retention values.

ACKNOWLEDGEMENTS

I would like to thank Dr. Raymond Janes, Western Michigan University Professor, for his help in planning and interpreting the results in this thesis.

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INTRODUCTION

The role of recycled fibers will grow rapidly during the 1990's because of increasing environmental demands and economics. This will mean that papermakers will have to incorporate higher percentages of recycled fibers into their virgin furnish. More quality problems will also occur due to decreased quality and higher variability in raw materials.

The objective of this project was to examine the effect of three different drying conditions upon the properties of the fines and how they, in turn, affect the strength of the paper and wet web. An assessment was made as to what initial properties the fines possessed and what resulting properties the fines possessed after recycling (drying).

THEORETICAL AND BACKGROUND

RECYCLED FIBER AND VIRGIN FIBER CHARACTERISTICS

Numerous studies have been conducted over the years using recycled fiber. The consensus is that recycled fibers exhibit lower mechanical properties than virgin fibers. The reason for this is that irreversible changes occur in the fiber during the drying process.

There are four fiber properties important to the strength of recycled fibers. They are fiber length, fiber strength, swelling/plasticity, and bonding potential. It is unclear how fiber strength is affected by drying, but it is well known that fiber length, plasticity, and bondability, are affected by drying. Recycled fibers are known to be less conformable than virgin fibers. This is due to stiffening of the fibers during drying. In effect, the fibers are case-hardened or "hornified". Because of this, the hydrogen bonding potential of the fibers is diminished for future bonding. The implication is that recycled fiber has the same fiber-fiber bond strength as virgin fiber, but the development of the bonded area on recycled fibers is less and hence, bond strength is lower.(1,2)

Earlier work by Avert and Weston (3) attributed the weakness of recycled papers to a loss of bond strength or area of bonds but not to a loss in fiber tensile strength. They stated the loss of of wet fiber plasticity or conformability caused by drying can be overcome by pressing. Because of the bulky nature of the recycled fibers, increased pressing is necessary to achieve the same density of never-dried pulp.

THE EFFECTS OF REFINING

Deficiencies in bonding can be partially overcome by refining. Refining fibrillates and plasticizes the fibers which improves their flexibility and increases their bonding area. In effect, the fibers are more able to swell and their water retention values can be recovered.(4)

There are three major actions of refining. The first is external fibrillation, which raises fibrils on the surface and consequently leads to more bondable contact points. The second is internal fibrillation, which loosens the internal fiber structure and promotes fiber flexibility. Internal fibrillation allows fibers to more easily collapse upon drying. In effect, it causes fiber shrinkage and imposes more permanent restrictions on reswelling the fibers. The last action of refining is fiber cutting/fines generation, which can negatively affect final paper strength and impede drainage. Recycled fibers respond best to low-intensity refining, which minimizes the fiber cutting action. Recycled fibers are also more prone to fiber fracture due to defects in the cell wall that have developed in the drying process.(4)

CHARACTERISTICS OF FINES

Their are many factors to consider when evaluating the properties of fines. Wood species, method of pulping, yield, refining conditions, and the specified size of the fines are very important variables.

Fines generally consist of both primary and secondary fines. Primary fines are dominant in unrefined pulp and are the result of the wood species and the pulping process. They consist of vessel segments (in hardwoods), parenchyma cells, ray cells and film-like fragments from outer fiber cell walls.(5) Secondary fines are dominant in refined pulp and are the result of the mechanical action on the fibers. They originate from the primary and secondary walls of the fibers.(6)

Primary fines are usually flake-like, chunky particles with a low specific surface area. It is generally agreed that they are not conducive to good fiber bonding.(7) Secondary fines, on the other hand, tend to be fibrillar in nature with a higher specific area and exhibit better bonding potential.(6) Jayme (8) found that fibrillar fines significantly increased tensile, burst, tear, fold, and density; fines reduced tear when used beyond a certain amount.

Ingmanson and Thode (9) found that fines greatly affected the drainage resistance of beaten pulps. The specific surface area of the fines increased with swelling and enabled the fines to become more flexible and conformable in a sheet. They stated that the major role of fines and surface development is improved bonding via the Campbell effect. Also, the fines are less effective as an equivalent surface area of fibrils.

Giertz (10) removed the fines from a refined bleached spruce sulfite and bleached birch sulfate pulps and found that density and tensile decreased, and light scattering increased. Results showed that the fines increased bonding which was attributed to stronger Campbell's forces.

Richardson (11) studied the "ultra-fines" from a NSSC hardwood pulp and their effects on paper strength properties and drainage rates. Fines (-200mesh) were fractionated into five classes: fines larger than 100 microns, fines between 85 and 100 microns, fines between 60 and 85 microns, fines between 20 and 60 microns, and fines smaller than 20 microns. Results showed that with the addition of fines, burst and tensile strength increased. Also, decreasing the size of the fines resulted in higher strength properties. However, drainage time increased significantly. It was felt that strength improvement was possibly sufficient to justify this loss in drainage time with the exception of the fines smaller than 20 microns.

In a study of spruce thermomechanical pulp, Corson (12) found that increasing fines content resulted in increases in density, tensile index, wet web tensile index, and scattering coefficient. Beyond a maximum fines content, tensile index decreased. Corson also found that lower fines content were necessary to reach maximum strength when the longer fibers of the furnish were well refined.

In a study of groundwood and sulphite fines, Langins (13) found that these fines reached a maximum wet tensile strength when the stock consisted of approximately 50% by weight of fines. Further increases in fines content resulted in a sharp drop in wet tensile strength.

CHARACTERISTICS OF RECYCLED FINES

As stated previously, drying changes the properties of the fibers. As with fibers, the properties of the fines also exhibit changes. Hawes and Doshi (7) found that when recycled unbleached kraft fines were added to an unrefined recycled kraft pulp, significant increases in density and strength occured. Light scattering coefficient was not significantly affected, which indicated the fines were involved in bonding. It was also concluded that unrefined fibers were more responsive to fines addition than were refined fibers. This was directly related to the unrefined fibers poor flexibility and lesser ability to conform in the final paper.

Reeves (4) stated that the fines from recycled fibers do not have the same ability to reswell as do fines from virgin fiber. Recycled fines exhibit lower water retention values than virgin fines. The water retention values of fines cannot be recovered by refining like they can be for longer fibers. He also stated that recycled fines contribute little to strength and behave more like organic fillers and decrease drainage rate. This is questionable because the reason cited for this is based on the lower strength properties of a recycled furnish containing both longer fibers and fines.

De Ruvo and Htun (14) were able to show that the water retention value of fibers decreased 20-35% after drying. The severity of drying tended to accentuate this effect.

EFFECTS OF DRYING ON FIBER STRUCTURE

Yamauchi and Kibblewhite (15) studied the porous structure for thermomechanical (TMP) and bleached softwood kraft pulp. It was found that with air-drying, the relative micropore volumes (pores or voids within fiber wall or interfiber bonds that are accessible to mercury intrusion) decreased markedly for the kraft but not for the TMP. This was explained by the greater flexibility of the kraft fibers, which allowed greater extents of bonding and consolidation to develop within the interfiber bond regions. During the air-drying process, micropore volume is destroyed as Campbell forces develop between adjacent fibers and fines surfaces.

PRESENTATION OF PROBLEM

The impact of different drying conditions on the properties of fines is not well documented in the cited literature. The objective of this project was to utilize three different drying conditions to study the properties of fines as they affect bonding in the wet web and final paper. Resulting properties of the fines were also examined after recycling. The three different drying conditions were: force-dried to 0% moisture, force-dried to 6% moisture, and air-dried to 6% moisture.

EXPERIMENTAL

EXPERIMENTAL DESIGN

This project consisted of studying the effect of different drying conditions on the fines in the paper by examining their properties for fines-free paper and fines-containing paper. The percentage change in each property as caused by the fines was examined for each drying level. Also, the percentage change in each property as caused by recycling was examined for each drying level.

The first phase of this project was to remove the fines from half of the original furnish by using the Bauer McNett. Next, fines-free and fines-containing handsheets were made on the British Sheet Mold and dried under three different conditions: air-dry to 6% moisture, force-dried to 6% moisture, and force dried to 0% moisture.

The handsheets were than tested for brightness, opacity, absorption coefficient, scattering coefficient, density, and tensile. Also tests were performed on the original pulp furnish to determine CSF, drainage time, wet-web strength, and water retention value. These tests were selected to determine the degree on bonding and influence or activity of the fines.

After drying (recycling) the handsheets, the same paper and pulp tests were performed to see which drying condition affected the properties of the fines the most.

EXPERIMENTAL PROCEDURE

Pulp preparation

A Canadian bleached kraft softwood market pulp with an initial moisture content of 12% was used to perform this study. Two standard Valley beater runs were performed following Tappi Standard T-200 om-85 (16). Refining time for both beater runs was 138 minutes and a final Canadian Standard Freeness of 384 ml was achieved. After refining was complete, both beaters were combined to achieve a constant pulp source.

Fines removal

Approximately half of the pulp was used for fiber classification and fines removal. Fines were removed from the pulp using the Bauer-McNett classifier as stated in T233cm-82 (17). Fines are defined as anything passing through a 200 mesh screen. The actual percentage of fines in the stock was found to be 10.2%.

The long fibered portion (greater than 200 mesh) was collected from each individual compartment with a muslin cloth bag. The fiber fractions were then combined, diluted to 0.3% consistency, and thoroughly mixed to achieve a uniform slurry.

Control stock tests

A series of tests was performed on both the classified and unclassified stocks. Wet-web strength, drainage, stock freeness, and centrifugal water retention values were evaluated for each stock.

Wet-web strength was evaluated using the Brecht initial wet strength tester. Six samples (each 30mm by 94mm) from six different sheets were tested at approximately 7 and 17% consistency and a linear regression was performed to find the best fit line. The value obtained at 20% consistency was used as a standard of comparison. The samples were obtained off a 150 mesh screen on the Noble and Wood Handsheet machine. The 7% sample was obtained without pressing and the 17% sample was obtained with very light pressing. Exact consistencies were determined by using a pre-weighed sealed container to obtain the wet weight of the sample before it was tested. After testing, the oven-dry weight of the sample was obtained using a hot-plate.

The drainage of the stock, or slowness, was evaluated in the British Sheet Mold by measuring the time with a stopwatch for all the free water to drain from the pulp suspension. The procedure listed in T221om-81 was followed (18). Ten determinations were made for each stock. Also, stock freeness was measured using the Canadian Standard Freeness tester following T227om-85 (19).

Water retention values were determined using a laboratory centrifuge. Approximately one gram of oven-dry fiber in a 0.3 % solution was drained with the use of an air-vacuum flask. The cup containing the fiber was then placed in a sealed plastic jacket and centrifuged for 30 minutes at 900 times the force of gravity. Upon completion, the sample was weighed to obtain the wet weight and then placed in an oven at 105 degrees Celsius for 24 hours to determine the oven-dry weight. The water retention value was taken to be the difference of the oven-dry and wet weight divided by the oven-dry weight. Three samples were tested for each stock.

Handsheet production and drying conditions

All handsheets in this project were produced on the British Handsheet Mold and couched off the wire with two sheets of blotter paper. In order to more easily control the final moisture of the sheet upon drying, the Noble & Wood press was selected over the conventional platen press. The consistency of the sheet leaving the press was 24-25%.

Three different drying levels were used for all handsheets. The first set of handsheets was placed on the plates in drying rings, and allowed to air-dry. The second set was force dried to 6% moisture on the Noble & Wood dryer. The temperature of the dryer can was 250 degrees Fahrenheit. The sheet was allowed to pass through one time only. The third set was force dried to a moisture content as low as possible and assumed to be oven-dry. This required at least three passes around the dryer can.

All sheets were placed in the standard conditioning room (73 F,, 50% R.H) for at least 24 hours prior to further testing. Overall, there were six sets of handsheets prepared, three each for both the fractionated and unfractionated stock.

Approximate moisture contents of the 6% force-dry sheets were determined by weighing the sheets after conditioning. Subsequent testing was performed for the sheets that had weights approximately equivalent to their weight after one pass around the dryer can.

Physical and optical testing of handsheets

The handsheets were first tested to determine brightness and opacity using Tappi Standards T425om-86 and T452om-87 (20)(21). Scattering coefficients and absorption coefficients were calculated by the Brightness Meter by simply entering the average basis weight of each set of handsheets.

Caliper was then measured using Tappi Standard T411om-84 (22). Ten measurements were taken on single sheets using a motor-operated micrometer. The average caliper and basis weight were then used to calculate the density of each set of handsheets. Tensile index was determined using Tappi Standard T494om-81 (23). Eight tests were performed on eight different sheets for each set of handsheets.

Repulping of handsheets

After all tests were completed, the handsheets and scraps were soaked in deionized water overnight and then mixed by hand. Two 24g OD samples at 1.2% consistency were prepared for all six sets of handsheets. Disintegration was carried out in the British Disintegrater. All pulps were subjected to 15000 revolutions.

Recycled pulp testing

After disintegration, tests were again performed for each set to determine the wet-web strength, drainage, stock freeness, and centrifugal water retention values.

Recycled handsheet production and testing

Handsheets were produced as before and all sets were air-dried to obtain a better understanding of their initial drying effects. After conditioning, tests were again performed to determine brightness, opacity, scattering coefficient, absorption coefficient, density, and tensile index.

PRESENTATION OF RESULTS AND DISCUSSION

Results of this project are presented on pages 24-34 . Bar graphs contain the three different drying levels and include results for the furnish with fines (labeled) and without fines (not labeled). The impact of fines at each drying level were studied using the percentage change for each particular fiber property. Percentage changes as caused by the fines are given at the top of each bar in the figures. Table 1 summarizes these results. Table 2 summarizes the impact of recycling as compared to the original paper characteristics.

Data obtained in this experiment are listed in Appendices 1-20. Linear Regressions for the wet-web strength are given in Appendices 21-28.

BRIGHTNESS

Figure 1 shows the effect of fines on brightness. It is evident that fines play a large role in brightness. Fines, in all cases, tended to lower brightness because they contribute to a denser, or more closely bonded sheet, and allow for less "open" interfaces to scatter light. The fines from the air-dry handsheets decreased the brightness the most (10.4%). Absorption coefficients, shown in Figure 2, tended to reflect the results of brightness. Higher absorption coefficients resulted in lower brightness and vice versa.

OPACITY

Figure 3 illustrates the effect of fines on opacity at the three different drying levels. Opacity should decrease when fines are present because fines provide for a denser, more closely bonded sheet. This leaves fewer available interfaces to scatter light. Both force-dry conditions did not support this. The only noticeable effect on opacity was with the air-dry conditions. The opacity was significantly lower. It is more evident by examining Figure 4, which shows the effect of fines on scattering coefficient. The decrease in scattering coefficient was 8.8% and the scattering coefficient was significantly lower than at the other drying conditions. This tends to indicate that air-drying tended to engage the fines in more active bonding, thereby, inhibiting them from scattering light.

During the processing of the pulps, the fines may have picked up color from the iron in the water. This would raise the absorption coefficient. It was believed that opacity did not change much because of the compensating effects. Less light scattering and bonding both decrease opacity as fines are added. Absorption coefficient increases to raise opacity as fines are added.

DENSITY

Figure 5 shows the effect of the fines on paper density at the three different drying conditions. In general, fines tend to fill the voids in the sheet and increase the area of fiber-fiber bonding creating a more dense structure. The most significant increase in density (10.3%) is noted for the force-dry (0% moisture) handsheets. This indicates that the fines exhibit the most influence on density when force-dryed to 0% moisture. As stated previously, drying causes the fiber matrix to collapse. It appears that there is more fiber-fiber or fiber-fine bonding occuring as a result of the intense drying.

TENSILE INDEX

Figure 6 shows the effect of the fines on the tensile index of the paper at three different drying conditions. As previously stated the addition of fines greatly increases the bonding in the sheet structure due to the fines larger surface area and ability to "bridge" between the longer fibers. This serves to increase the tensile index.

As with density, the largest increase (33.1%) in tensile, as caused by the fines, occured during force-drying (0% moisture). Again, this is attributed to the drying collapsing the fiber structure and increasing bonding and strength of the final sheet.

For both sets of sheets dryed to 6% moisture, the fines contributed significantly less to tensile index, 24.3% and 18.9% for the force-dry (6% moisture) and air-dry (6% moisture) sheets, respectively. The pattern persists indicating that the wet fibers subject to harsh drying permit the fines to contribute the most to bonding strength.

Another outstanding feature of the graphics is that the air-dryed fibers gave the greatest tensile index. Increases in density which would account for this effect were not apparent. This tends to indicate that when heat was applied to the fiber matrix from an external source, the natural fiber bonding strength was adversely affected. Increases in density which would have accounted for this effect were not apparent. Air drying allows surface tension driving forces to act for a longer time on drying the fiber matrix. This gives more time for more bonds to occur.

RECYCLED PAPER BRIGHTNESS

Figures 7 and 8 show the effect of recycling and fines on brightness and absorption coefficient at the three different drying conditions. Results show, as before, that fines decreased brightness and increased absorption coefficient. Results also show a small reduction of brightness due to recycling. This was supported by larger absorption coefficients in two of three cases for the paper containing fines. This would be expected due to more iron absorption. The lone exception was believed to be in question.

RECYCLED PAPER OPACITY

Figures 9 and 10 show the effect of recycling and fines on opacity and scattering coefficient at the three different drying conditions. Scattering coefficient for paper containing fines did appear to decrease, but not as significantly as the original furnish. Again, the largest decrease (2.1%) in scattering coefficient occured for the air-dried recycled paper. This tended to indicate that recycling deactivated the bonding activity of the fines.

Results also show an increase in opacity and scattering coefficient due to recycling. Scattering coefficient increases because the fines are not as actively engaged in bonding. The scattering coefficient of the air-dried recycled paper containing fines suffered the most (decreased 19.6%) but was still higher than the force-dried paper scattering coefficient. Again, this indicated that the less harsh drying allowed the fines to be more active after recycling.

RECYCLED PAPER DENSITY

Figure 11 shows the effect of recycling and fines on paper density at the three different drying conditions. These results show the same trends as noted in the discussion on non-recycled paper density.

The major difference is that all the densities are lower (8-14%) upon recycling. This is expected because drying tends to alter individual fiber properties. The fibers are less conformable, or more stiff, and cannot approach each other as close as they could if they had never been dried.

Results indicate that the fines are much more active in two cases (both 6% moist. drying levels) and much less active in one case (force-dried to 0% moist.). But, density values started from lower values after recycling, so fines are more needed and therefore appear to be more effective after drying.

RECYCLED PAPER TENSILE INDEX

Figure 12 shows the effect of recycling and fines on tensile index at the three different drying conditions. These results show strikingly similar trends to the results of tensile index of non-recycled paper. The values for tensile index are all lower (23-33%) as would be expectd due to the impact of drying on the fibers and their lower bonding potential.

Again the force-dry (0% moist.) paper showed the highest increase (32.3%). This is due to the tensile index of the fines free sheet being so low. Fines are more necessary now and appear to be more effective. For the other drying condition, the fines contributed less, 16.6% for the force-dry (6% moist.) and 22.1% for the air-dry (6% moist.). The data imply that the fines and fibers retain their original characteristics after recycling.

The same feature, as before, existed for the air-dry handsheets upon recycling. The tensile index was over 12 % higher than at any other drying condition. This again was not accounted for in higher densities and indicated that air-drying allowed the natural bonding strength to develop more completely as compared to force-drying of the fiber network.

DRAINAGE

Figure 13 shows the effect of fines on drainage for the original pulp source. As expected, the pulp with fines drained about 69% slower. The high surface area of the fines tends to more easily fill the voids of the fiber mat which is being formed in the sheet mold. This impedes the flow of the free water through the mat.

Figure 14, which shows the effect of recycling and fines on drainage following the three different drying conditions, indicated that drying had little, if any, effect on drainage behavior. All drainage times increased slightly compared to the original pulp. This was most likely due to the disintegration process where the mechanical action may have created some additional fines.

Drainage is most affected by surface area and swollen volume. Any differences in fiber morphology caused by drying was too small to be measured in terms of drainage.

FREENESS

Figure 15 shows the effect of fines on stock freeness for the original pulp source. As expected, the fines slowed the rate of drainage and considerably lowered the Canadian Standard Freeness (CSF).

Figure 16 shows the effect of recycling and fines on stock freeness following the three different drying conditions. All values of CSF for the stock without fines were relatively the same as the original furnish CSF without fines. CSF decreased slightly from the initial CSF. Again, this slight decrease could be due to some fines being generated during the disintegration.

Major differences were evident in the stock containing fines. The highest fines-containing freeness (at 481 ml) occured for the force-dry (0% moisture) stock. It appears that the fines may have become so well bonded to the longer fibers, that the disintegration process may not have effectively dispersed them and the fines may have essentially become inactive. Similar trends were evident for the force-dry (6% moist.) and air-dry (6% moist.) stock, although to a much lesser degree for the air-dry stock.

This indicates that the fines are more active if not force-dryed. These observations appear to be directly related to the wet web strength characteristics.

WET-WEB STRENGTH

Figure 17 shows the effect of fines on wet-web strength for the original pulp source. Fines increased wet-web strength by about 27.1%.

Figure 18 shows the effect of the recycled fines on wet web strength following the three different drying conditions. As with tensile index, there are significant reductions in wet tensile after recycling. Although there were large uncertainties in this test, the mean values indicated a relationship. The data supports that the air-dry fines continued to contribute about 26.7% improvement in the wet-web strength, but the force-dry (0% moist.) fines contributed only 5.2%. The force-dry (6% moist.) fines were in between the extremes with a 13.8% contribution.

The drying conditions appear to have no effect on the long fibered stock alone, but more so on the stock containing fines.

The likely explanation for this was alluded to in the freeness discussion. The fines from hard drying are less active and possibly bonded to either other fines or longer fibers. The fines are no longer able to assume as large a role in bonding as they could if their whole surface area was available for bonding. Therefore, bonding potential is decreased and so is wet web strength. The air-dry or less severe drying tended to produce more active fines upon disintegration. Therefore, they contributed almost the same bonding potential as never-dried stock.

WATER RETENTION VALUES

Figure 19 shows the effect of fines on the water retention value (WRV) for the never-dried pulp. The fines contribute to a higher WRV because their high surface area allows them to retain more water.

Figure 20 shows the effect of recycling and fines on WRV at the three different drying conditions. For all recycled pulp, the WRV's dropped. This is expected because drying causes stiffening of the cellulose material and closing of the pores in the cell wall. In effect, the cellulose material is less hydrophillic, or has a lower affinity for water. The results are deceiving in that the force-dry (0% moist.) fines appear to increase WRV by 16.5%. This appears as a high percentage because the force-dried fines free pulp WRV's were so low (2.30). Even inactive fines raise WRV.

It must be noted that there is less than 5% difference between all values for stock containing fines and similarly for the stock without fines. From a statistical point, there is no conclusive evidence as to the effect of drying on WRV. As previously stated, De Ruvo and Htun stated that WRV of fibers decreases after drying with the severity of drying accentuating the loss. Therefore, it was expected that air-drying, because it is the least harsh drying method, would cause the fines to retain more of their hydrophillic nature and exhibit higher WRV's.

TABLE 1

The Effect of Fines on Paper Properties

[% change due to fines for (original / recycled paper)]

	FD- 0% moist.	FD- 6% moist.	AD- 6% moist.
Brightness	-6.0 / -8.9	-9.2 / -8.4	-10.4 / -7.1
Abs. Coeff.	25.0 / 64.3	87.5 / 61.5	48.0 / 60.0
Opacity	-0.2 / 0.4	0.1 / 0.4	-3.7 / -0.7
Scatt. Coeff.	-1.4 / -0.1	-3.1 / -0.9	-8.8 / -2.1
Density	10.3 / 7.3	1.8 / 8.2	2.3 / 5.7
Tensile	33.1 / 32.3	24.3 / 16.6	18.9 / 22.1

TABLE 2

The Effect of Recycling on Paper Properties
with and without Fines

[% change due to recycling for paper (with fines / without fines)]

	FD- 0% moist.	FD- 6% moist.	AD- 6% moist.
Brightness	-3.3 / -1.9	-0.4 / -1.4	2.7 / -2.2
Abs. Coeff.	31.0 / 0.0	-6.7 / 8.3	8.1 / 0.0
Opacity	3.5 / 2.9	3.3 / 3.0	7.1 / 4.4
Scatt. Coeff.	3.7 / 2.4	9.4 / 6.2	19.6 / 11.4
Density	-14.4 / -12.0	-7.9 / -13.4	-10.9 / -13.7
Tensile	-33.0 / -32.6	-27.9 / -23.1	-27.6 / -29.5

Figure 1: The Effect of Fines on Brightness

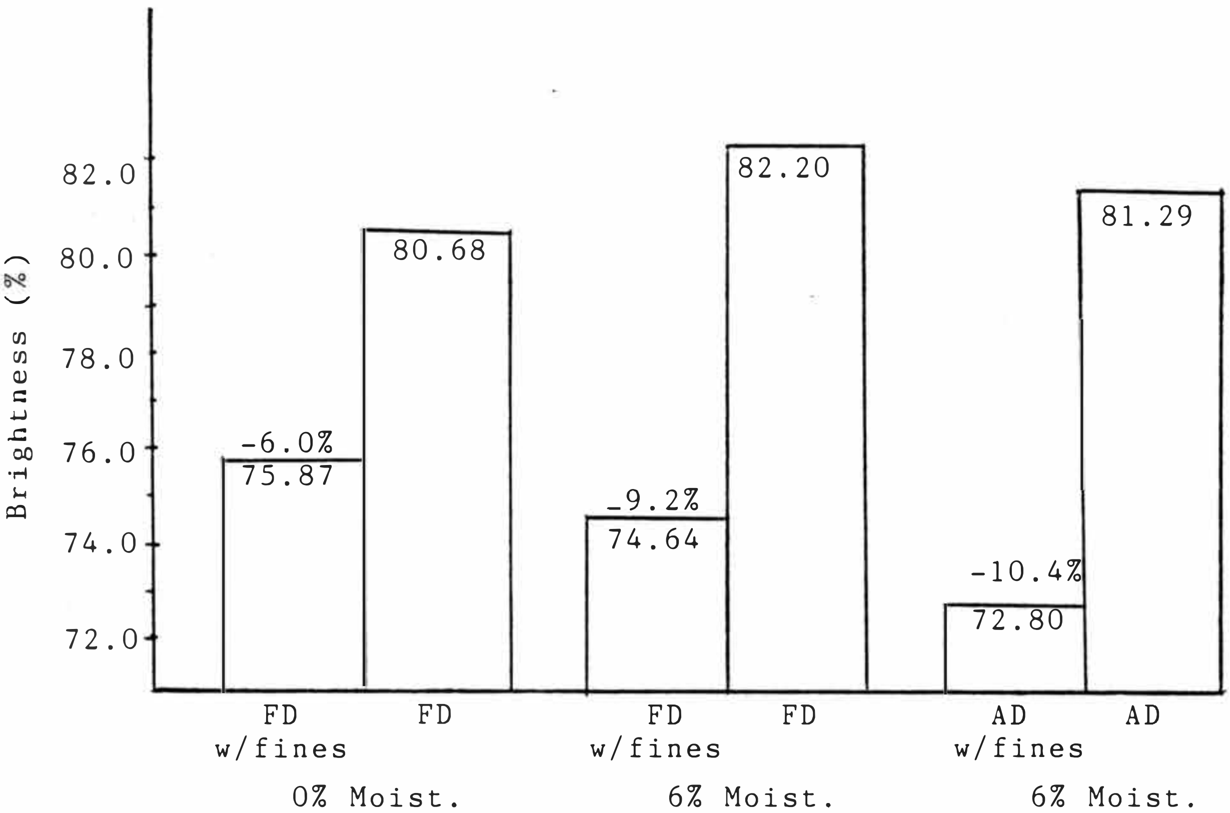


Figure 2: The Effect of Fines on Absorption Coefficient

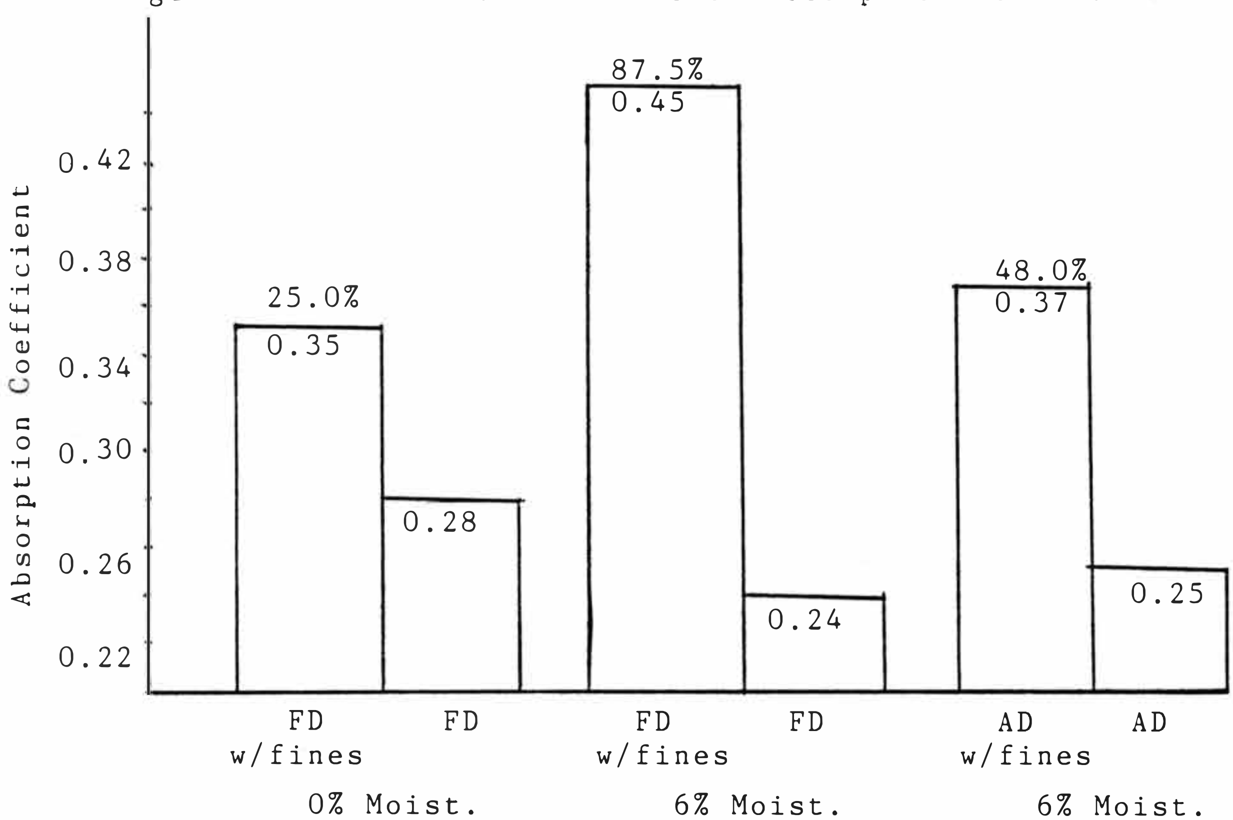


Figure 3: The Effect of Fines on Opacity

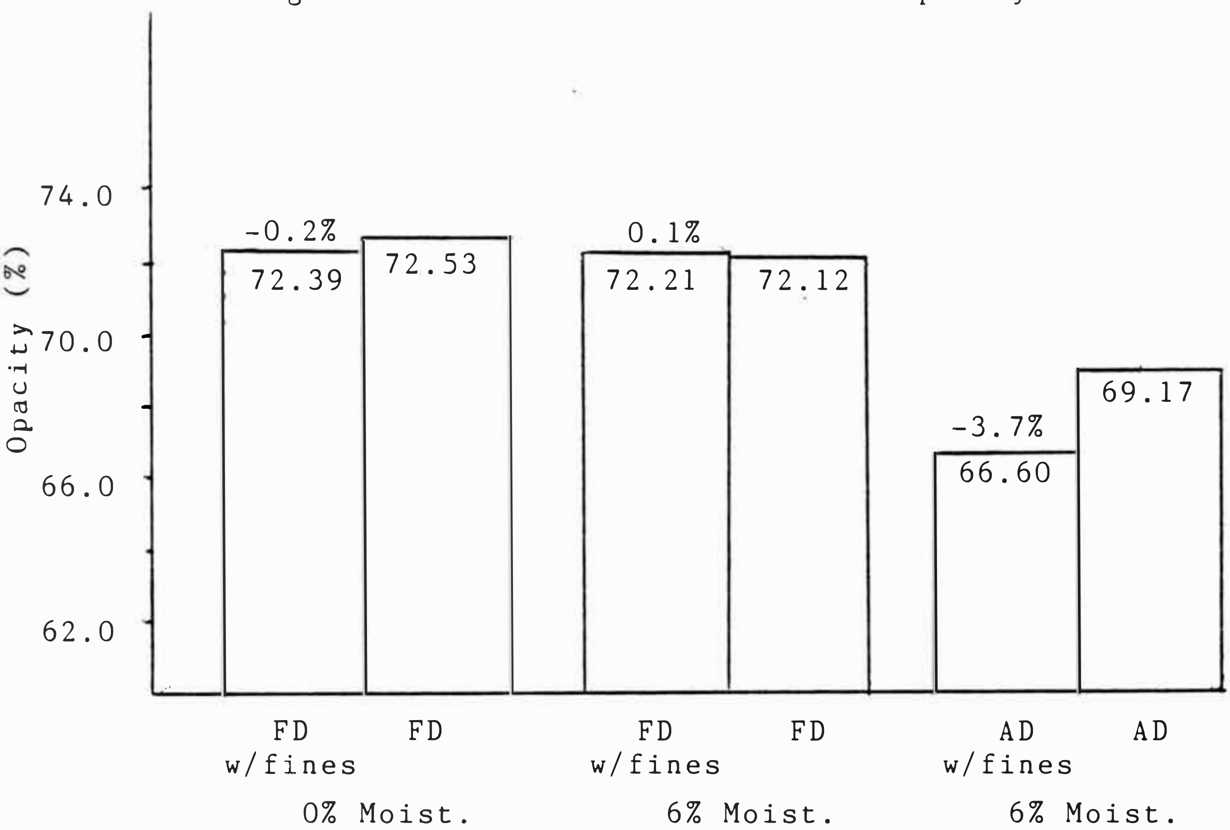


Figure 4: The Effect of Fines on Scattering Coefficient

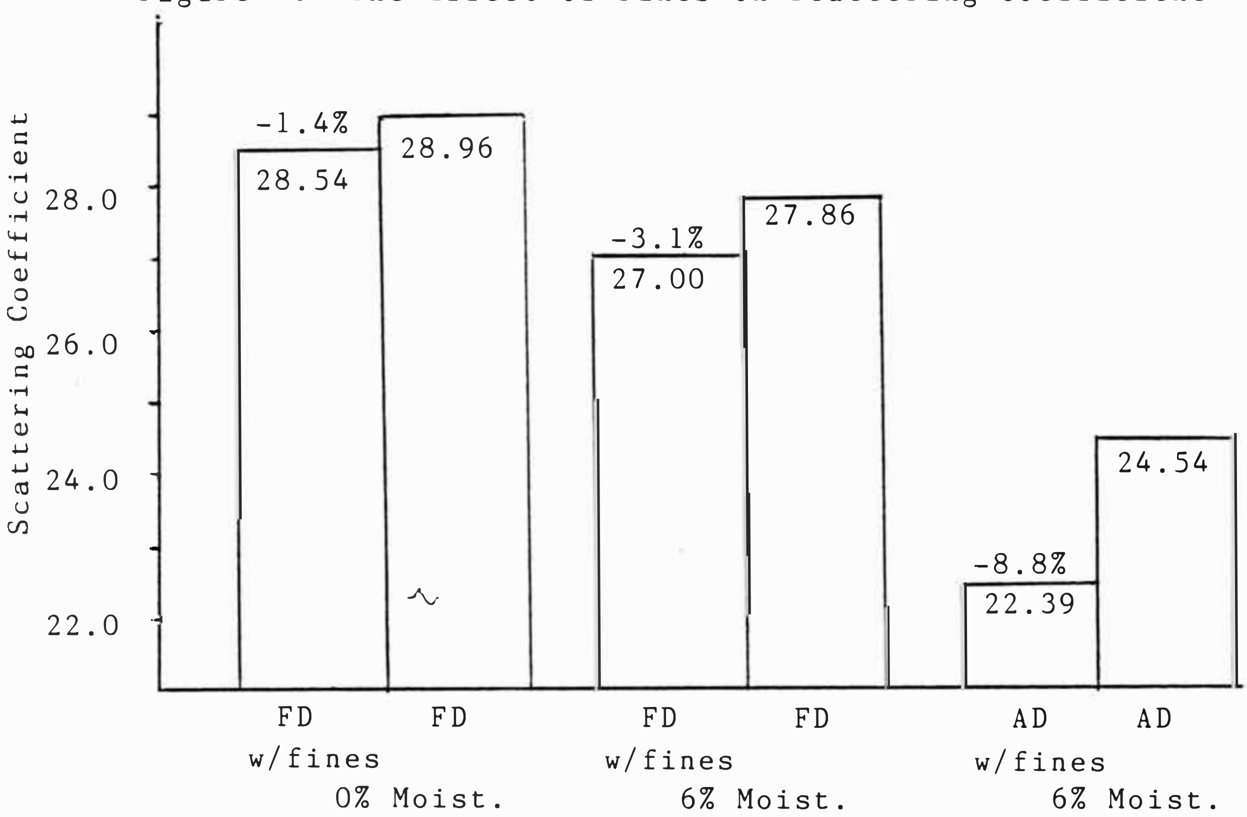


Figure 5: The Effect of Fines on Density

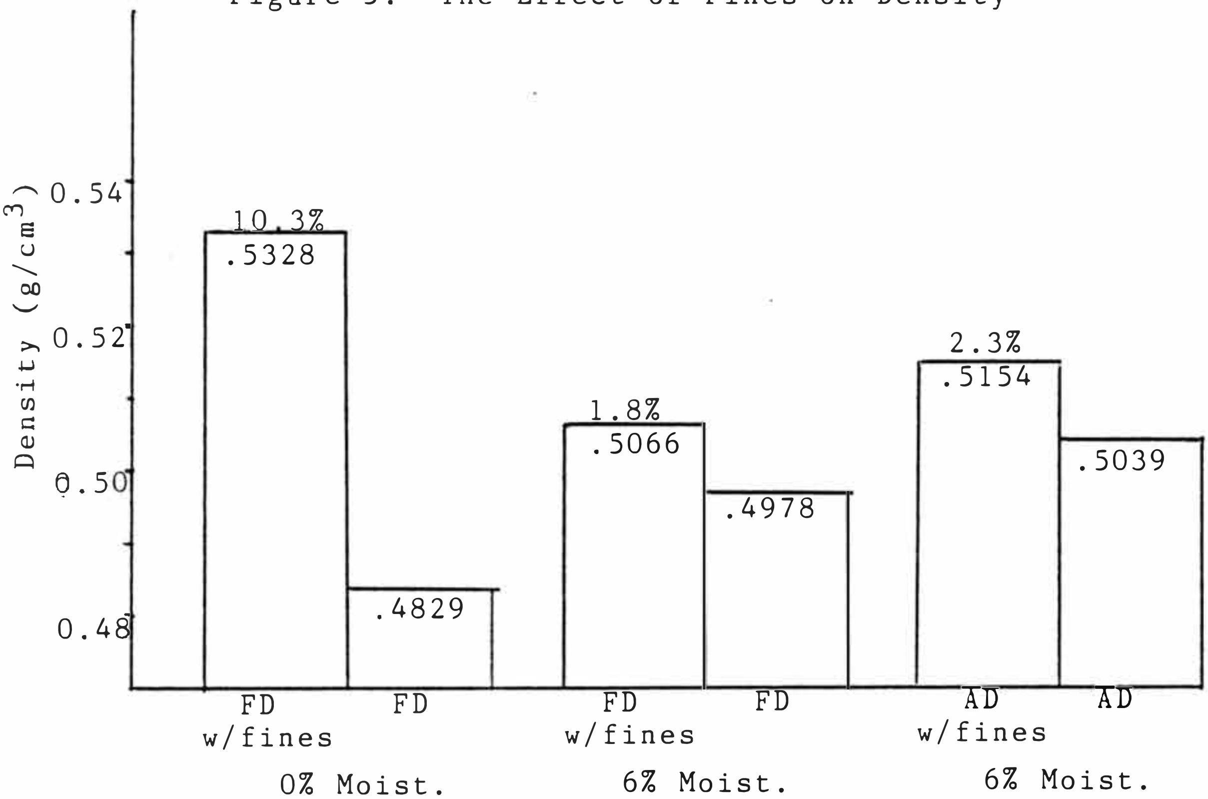


Figure 6: The Effect of Fines on Tensile Index

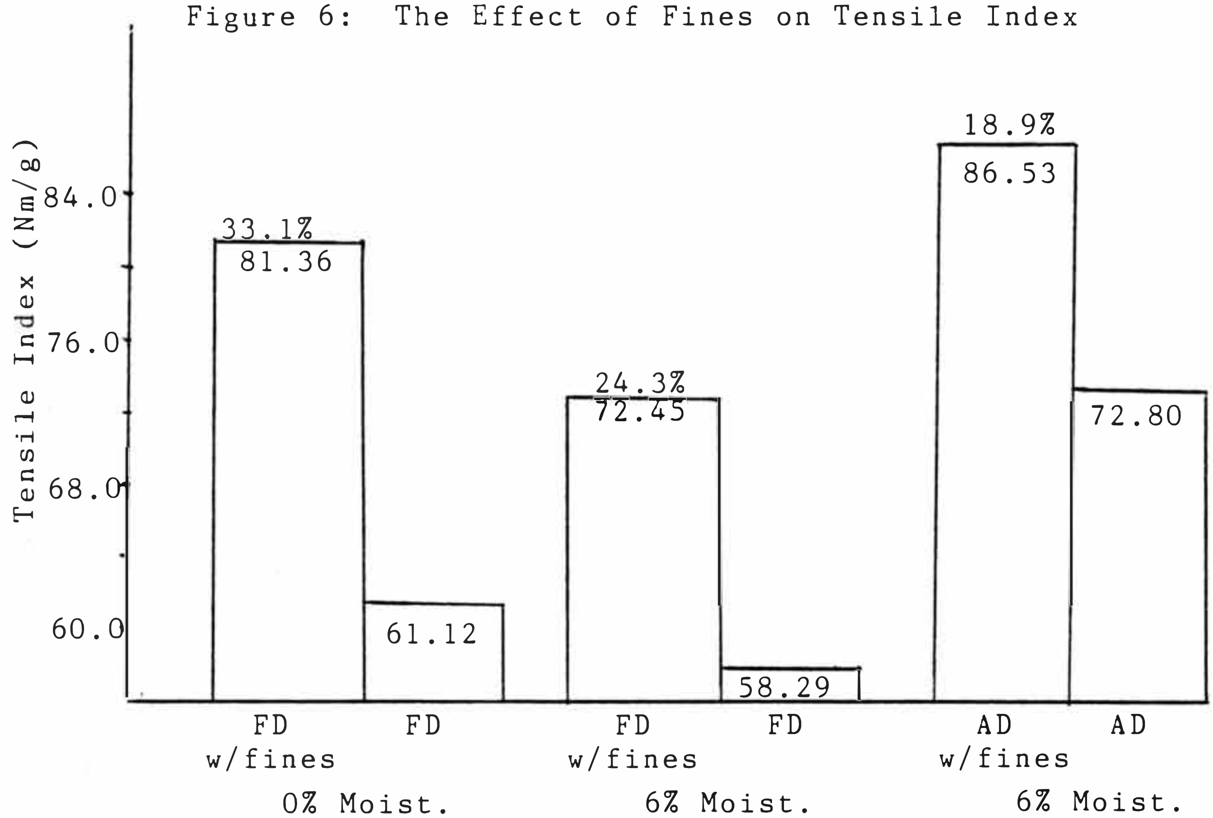


Figure 7: The Effect of Recycling and Fines on Brightness

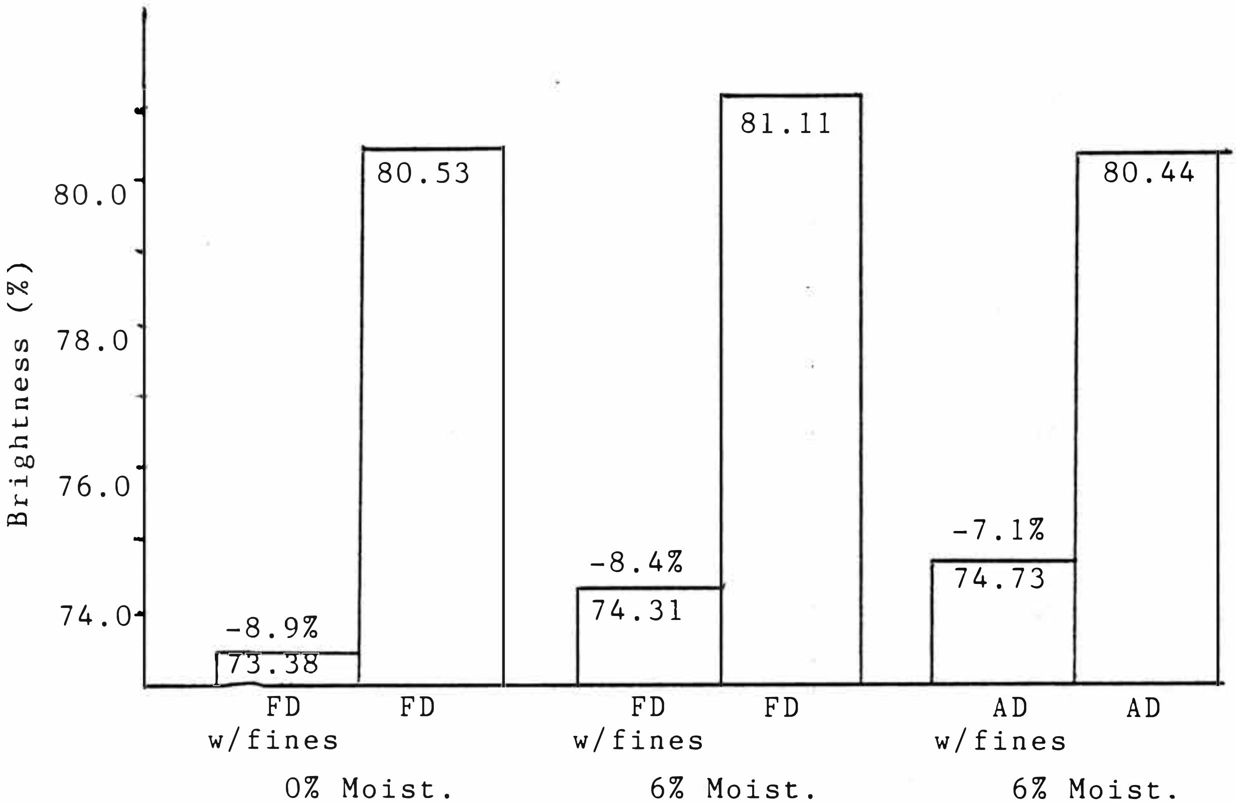


Figure 8: The Effect of Recycling and Fines on Absorption Coefficient

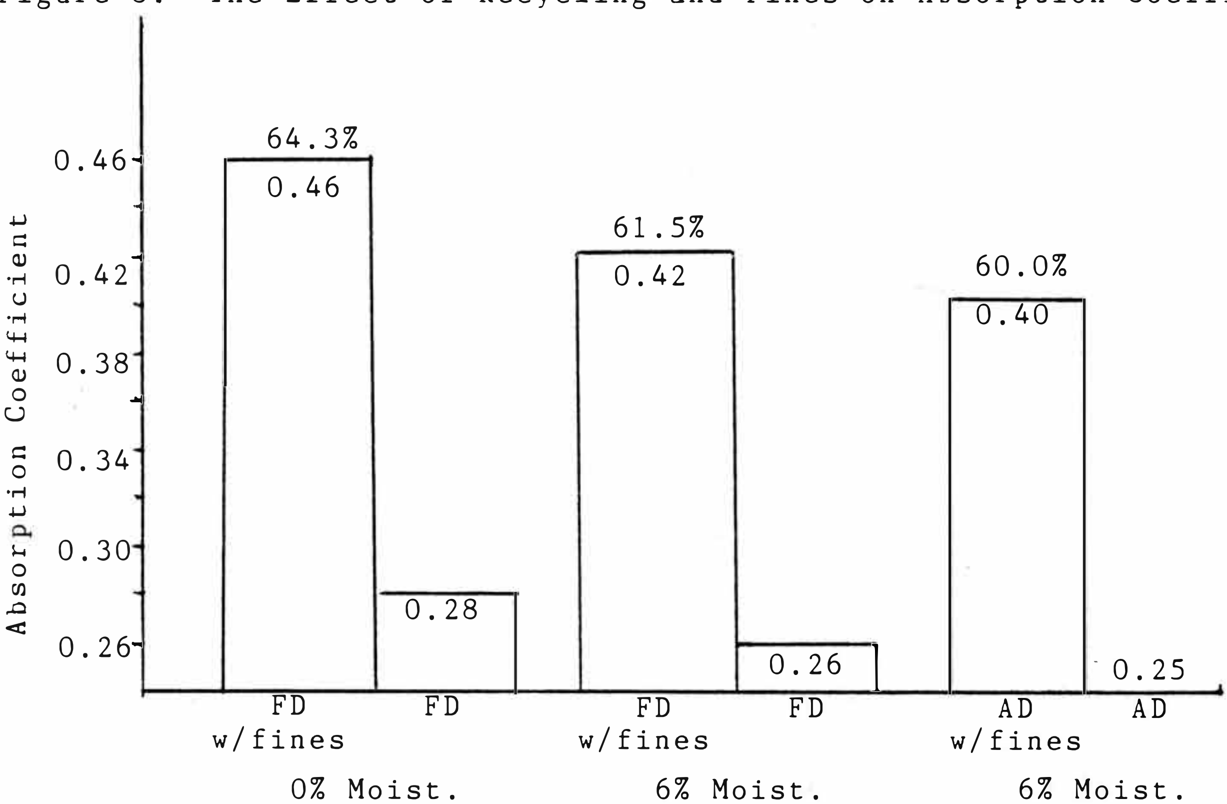


Figure 9: The Effect of Recycling and Fines on Opacity

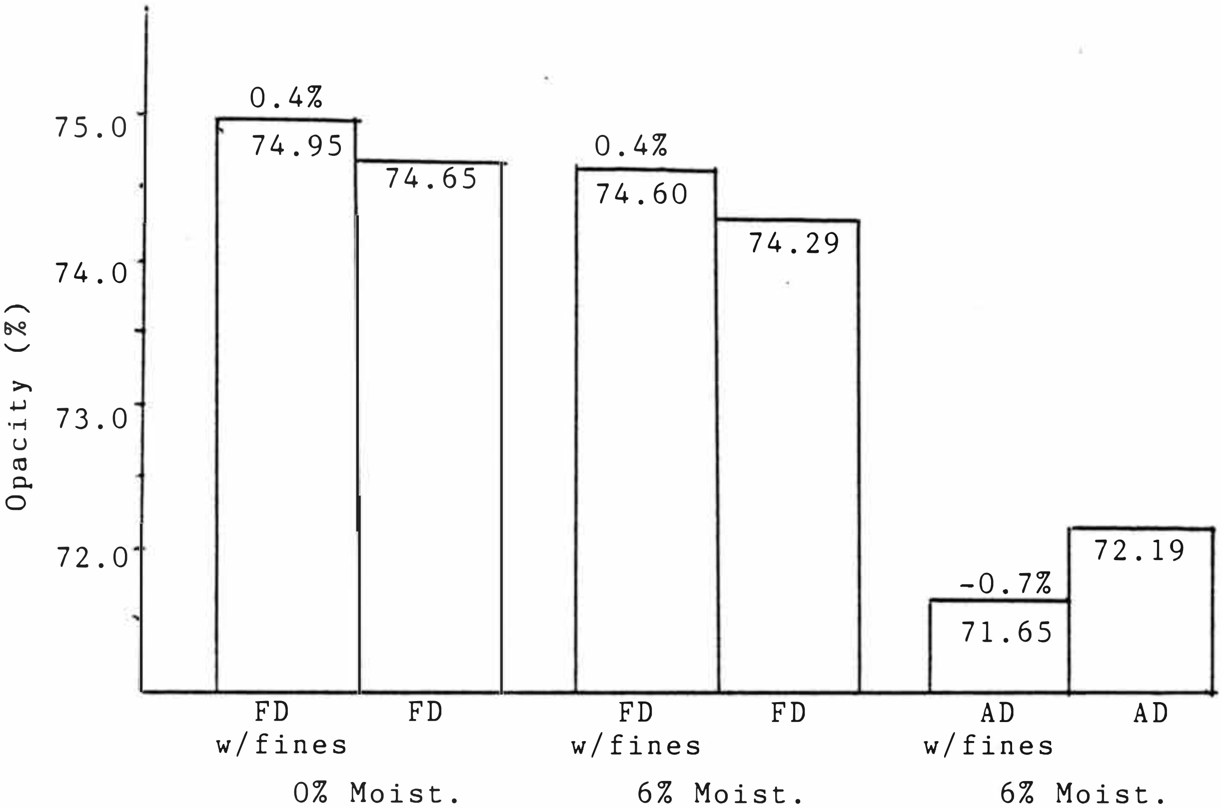


Figure 10: The Effect of Recycling and Fines on Scattering Coefficient

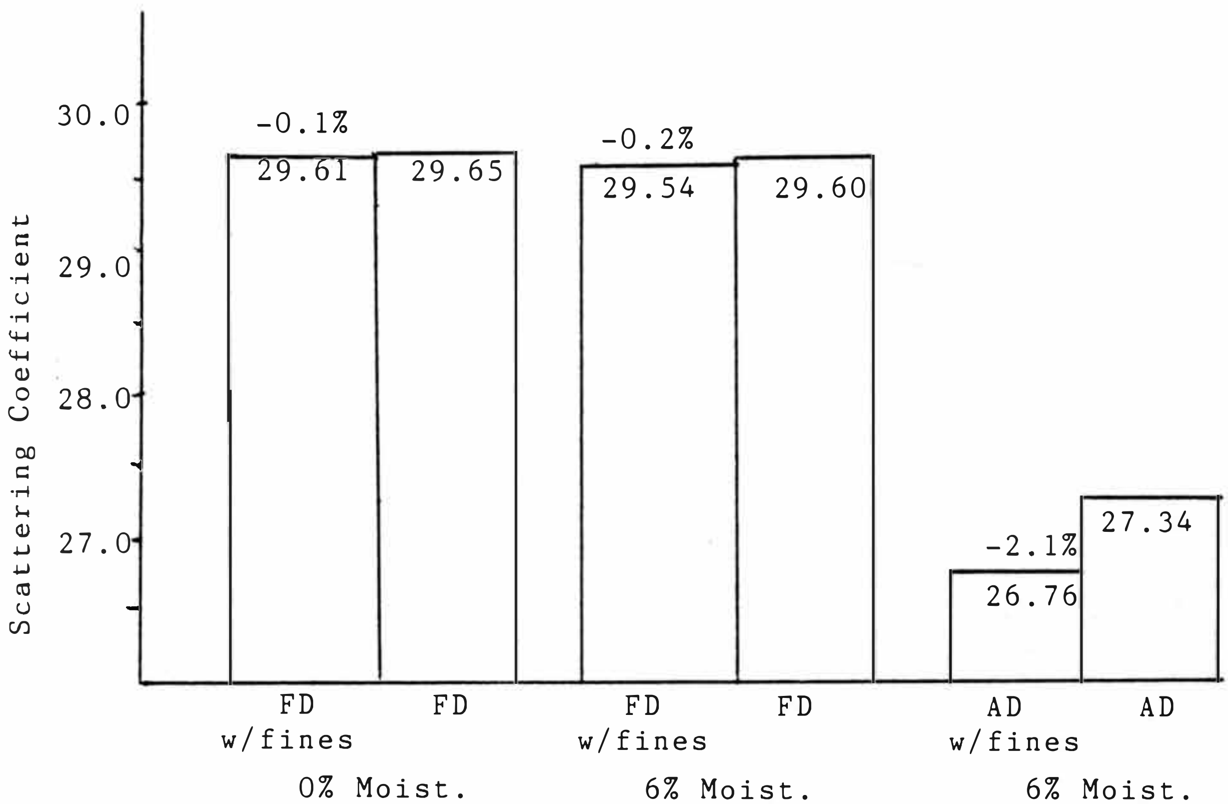


Figure 11: The Effect of Recycling and Fines on Density

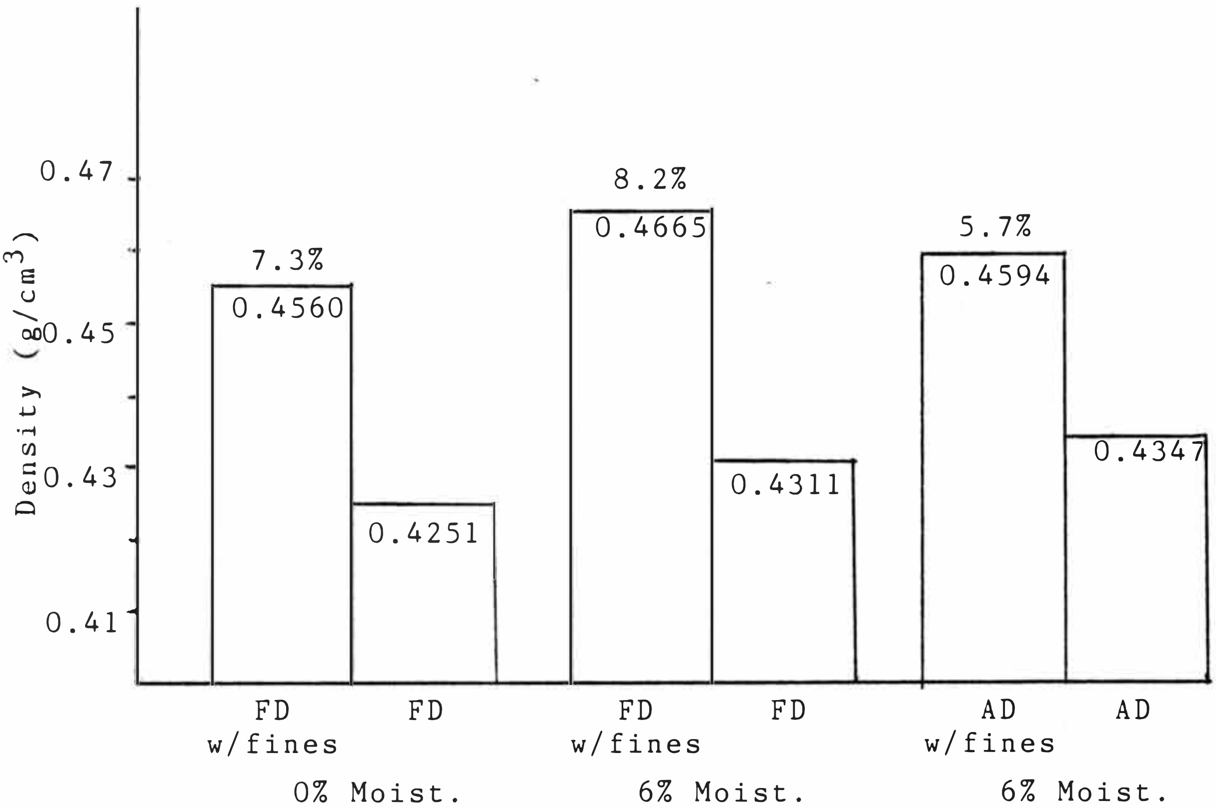


Figure 12: The Effect of Recycling and Fines on Tensile Index

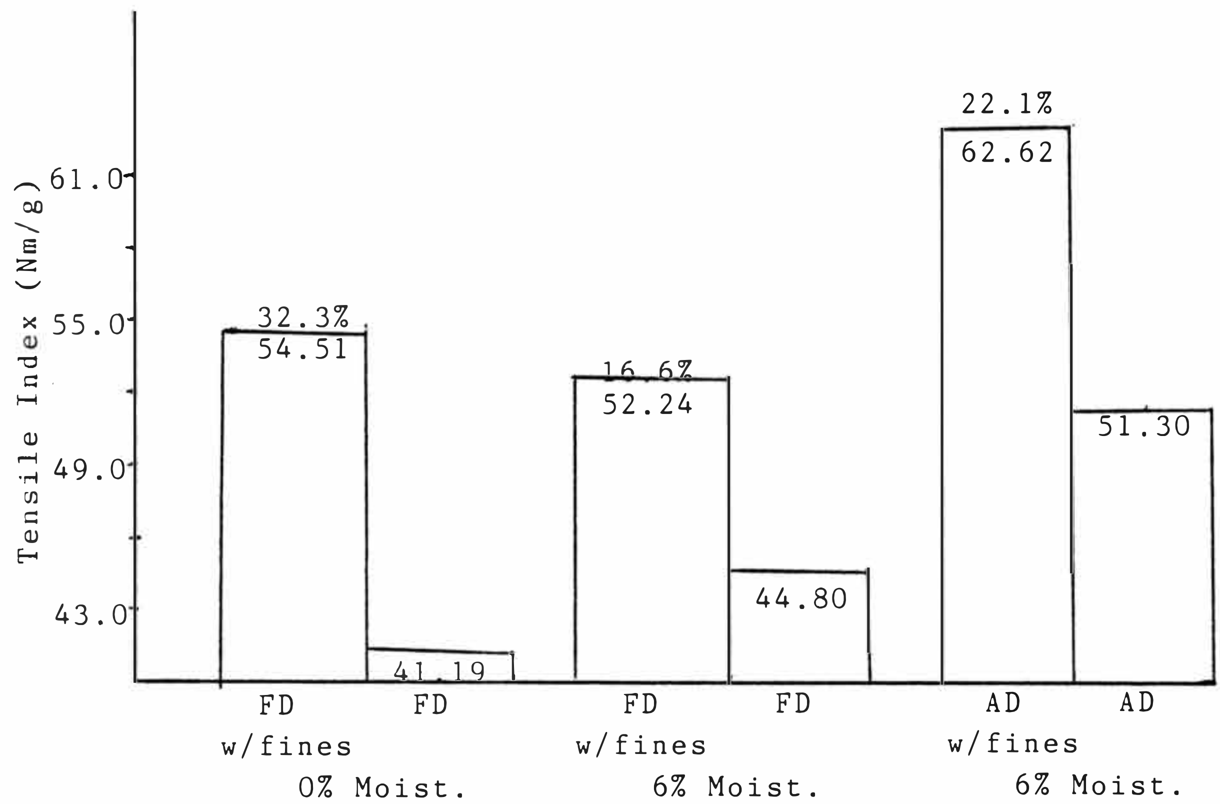


Figure 13: The Effect of Fines on Drainage of Original Pulp Source

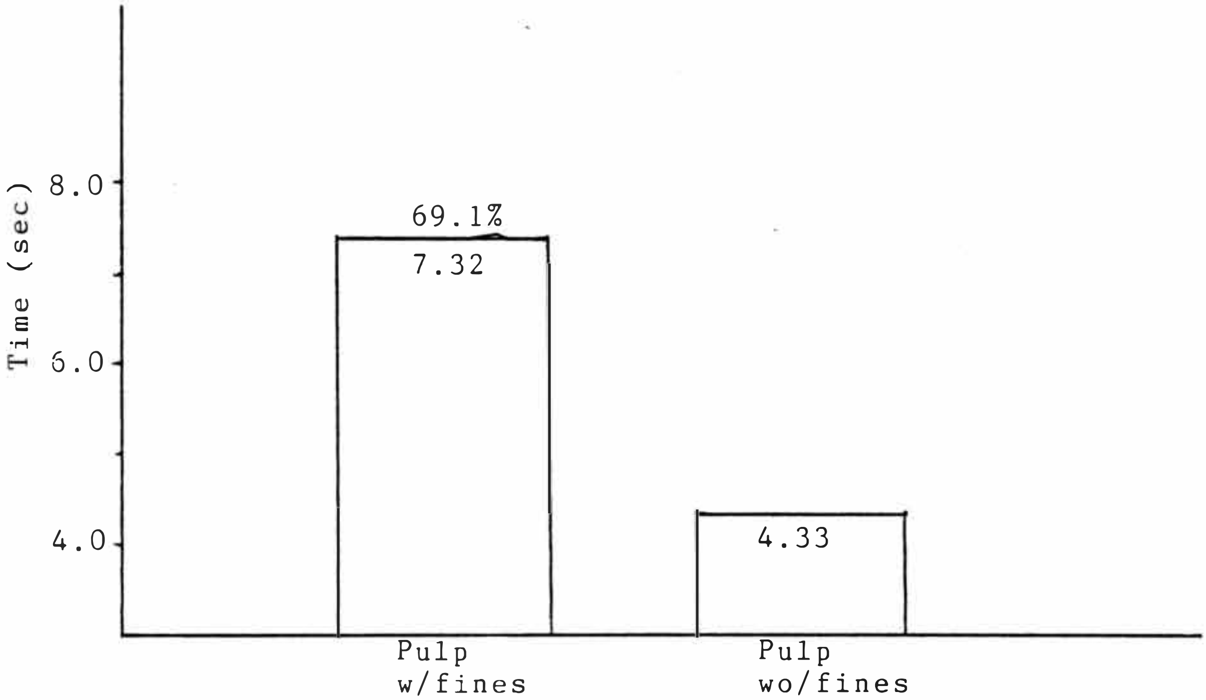


Figure 14: The Effect of Recycling and Fines on Drainage

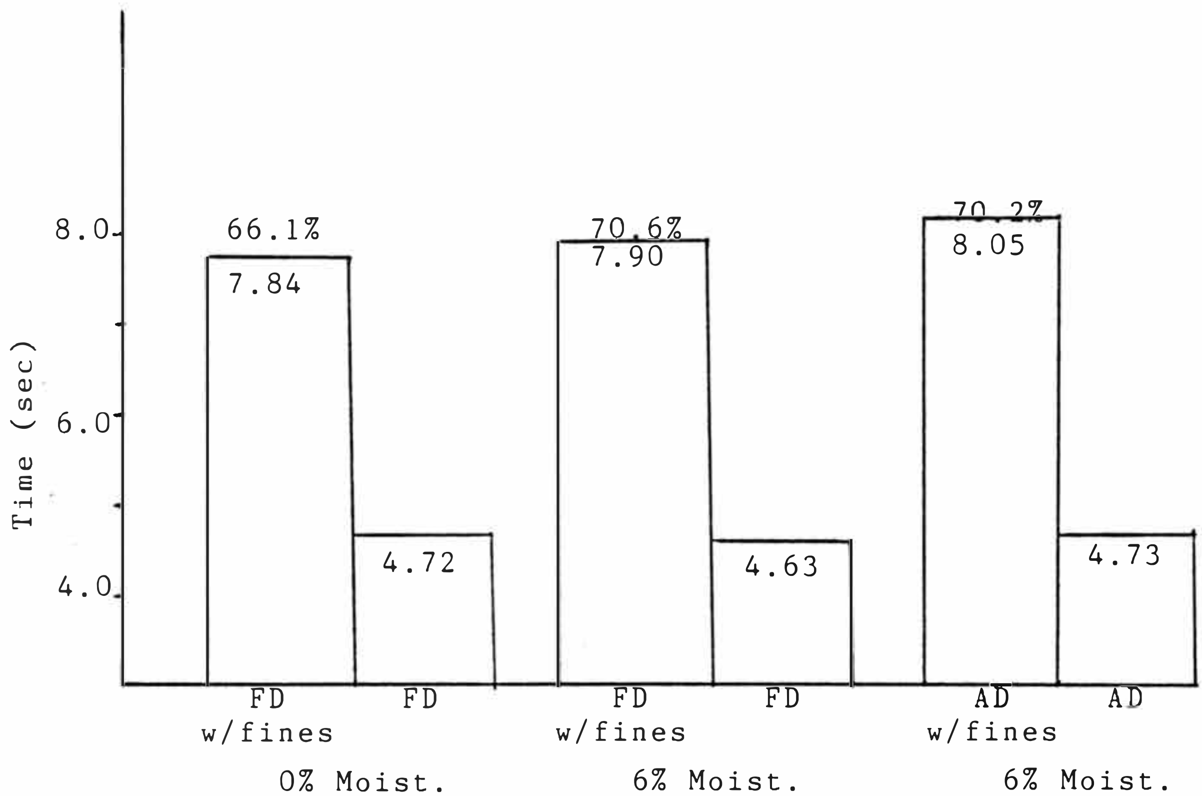


Figure 15: The Effect of Fines on Stock Freeness of Original Pulp Source

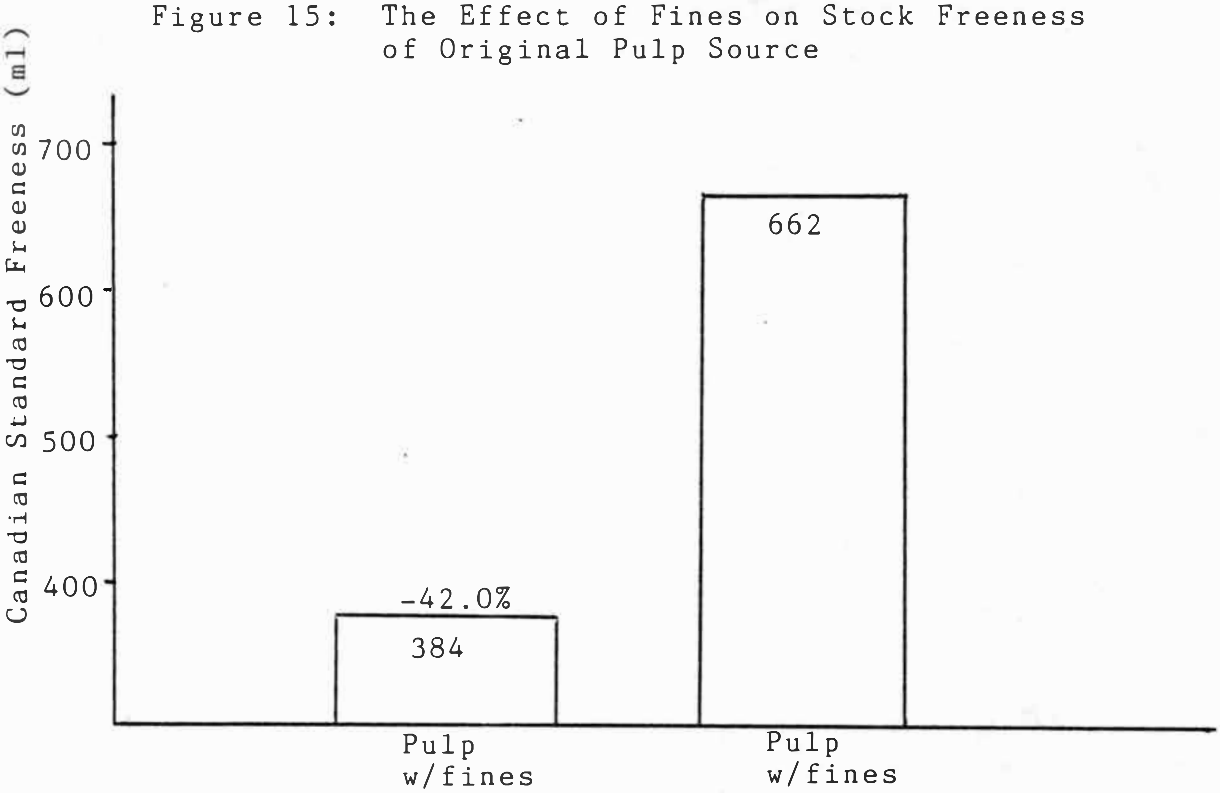


Figure 16: The Effect of Recycling and Fines on Stock Freeness

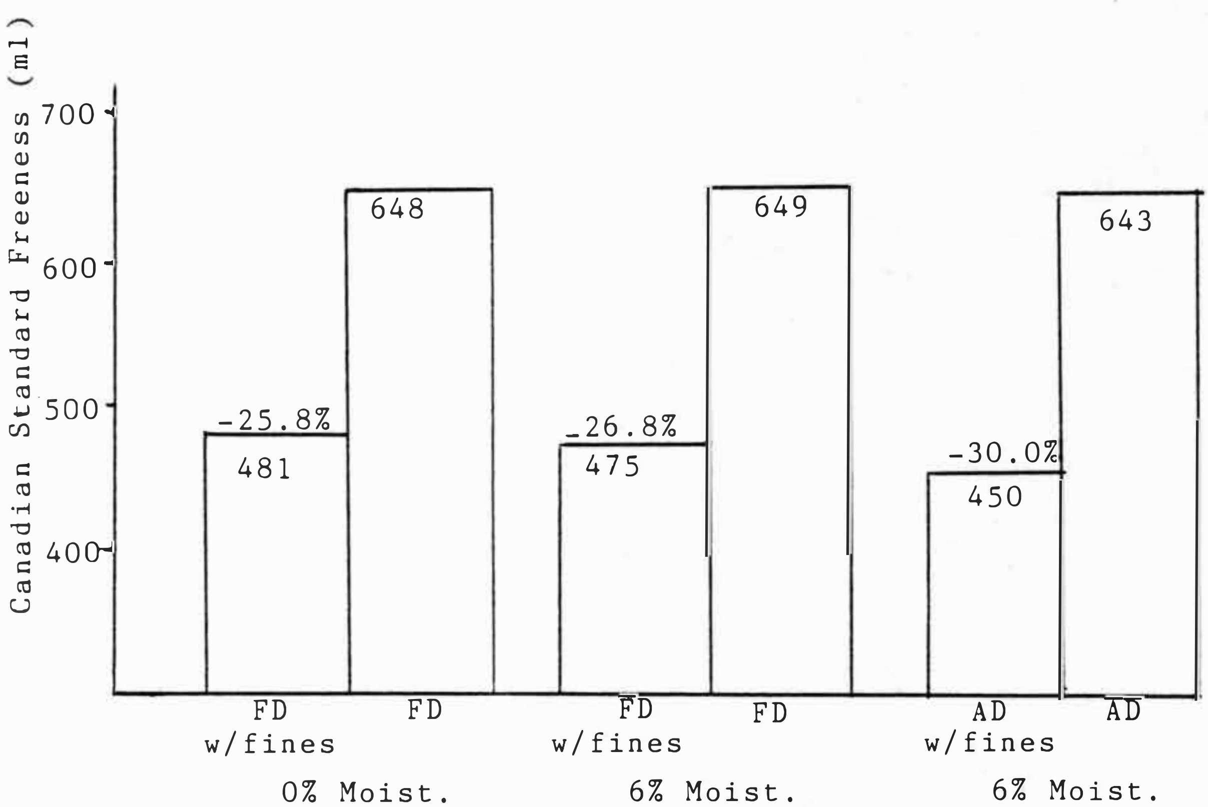


Figure 17: The Effect of Fines on Wet-web Strength of Original Pulp Source

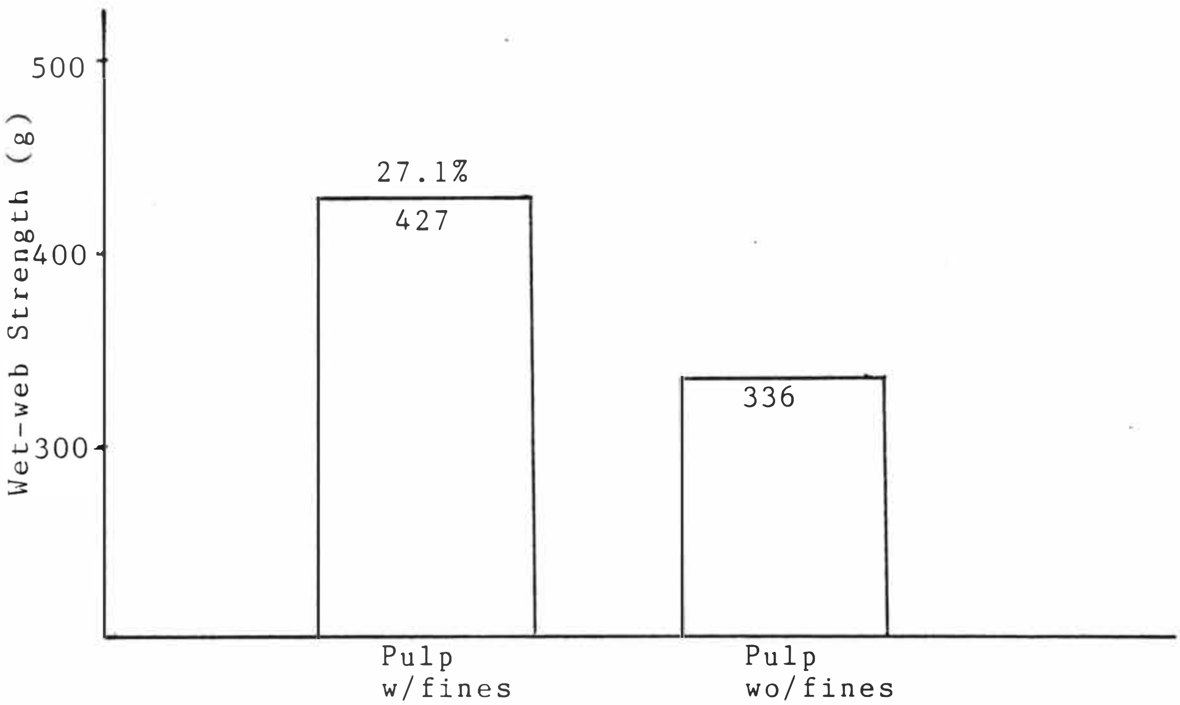


Figure 18: The Effect of Recycling and Fines on Wet-web Strength

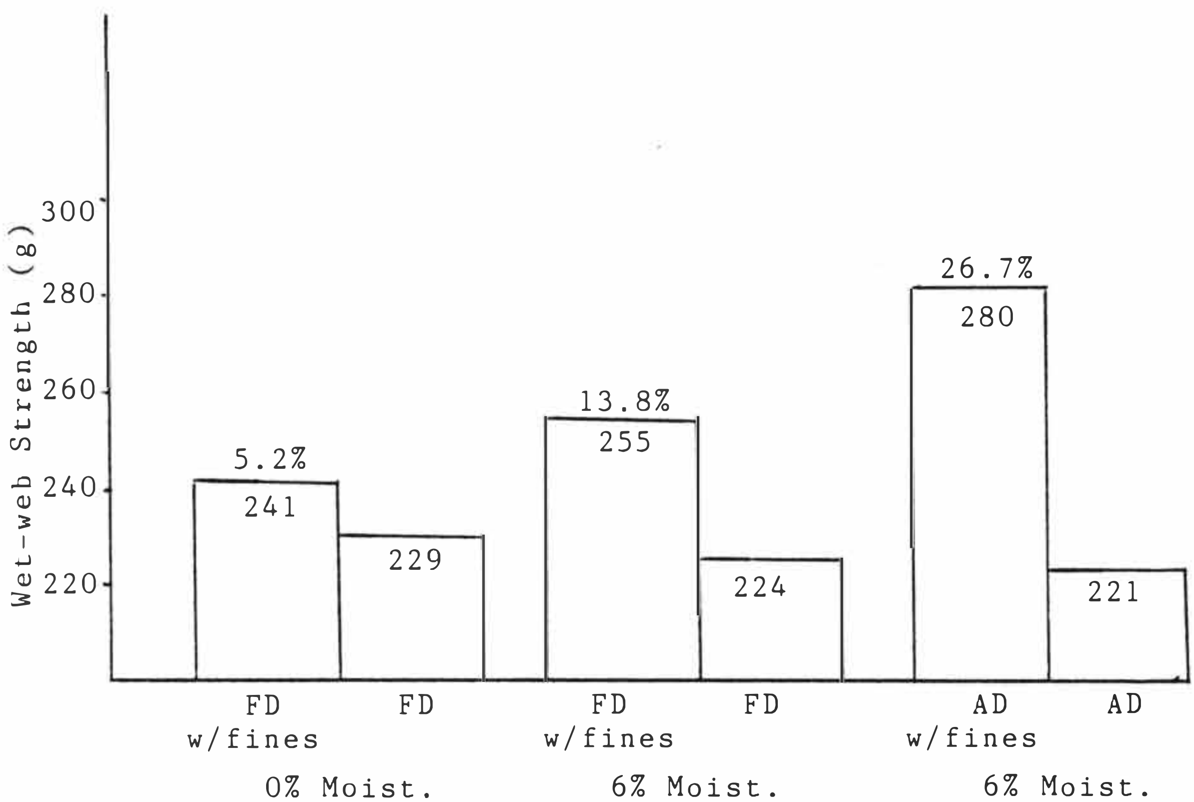


Figure 19: The Effect of Fines on Water Retention Value of Original Pulp Source

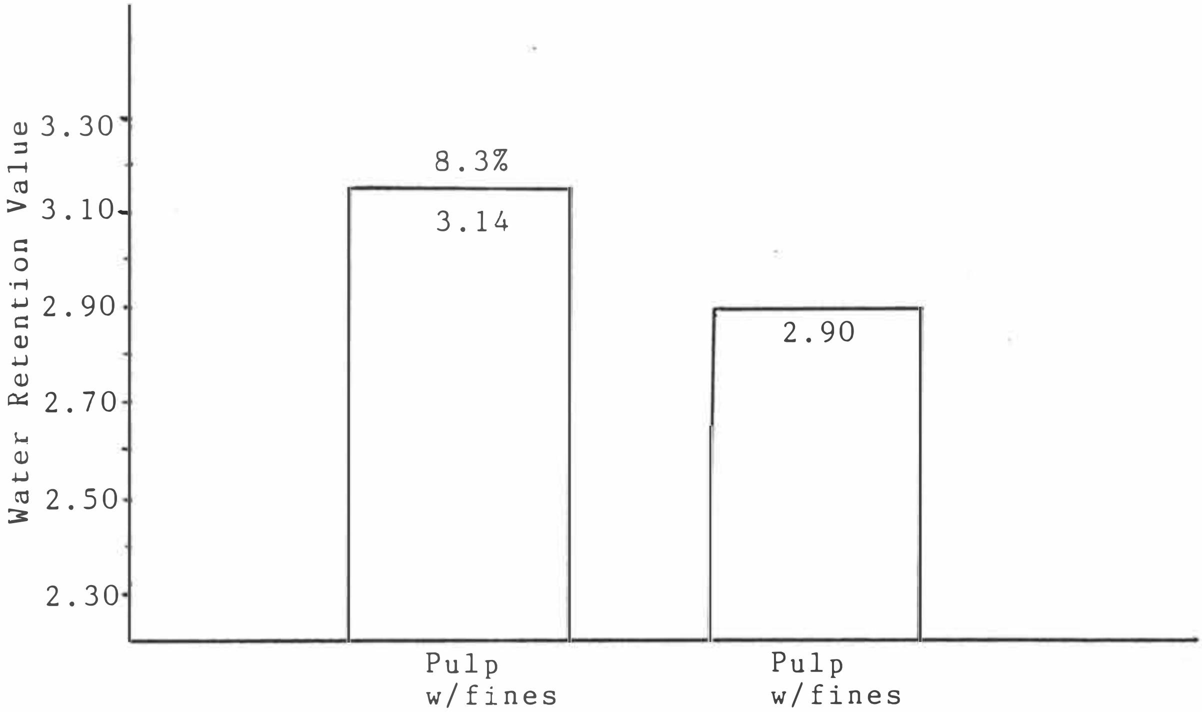
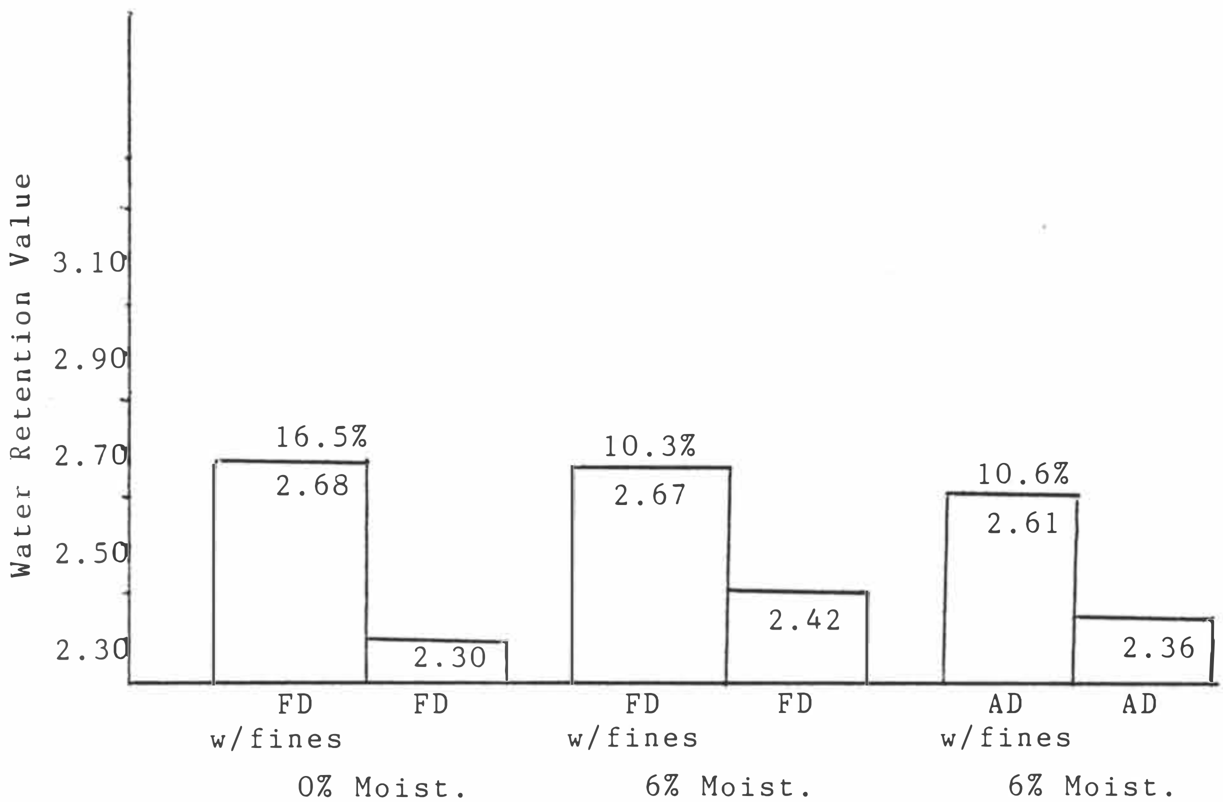


Figure 20: The Effect of Recycling and Fines on Water Retention Value



SUMMARY OF RESULTS

- Brightness decreased when fines were present and upon recycling.
- Fines lowered scattering coefficient with air-dried paper containing fines decreasing the most.
- Recycling increased scattering coefficient and opacity.
- Opacity did not change with the addition of fines because the increased bonding, which decreased opacity, was offset by higher absorption coefficients, which increased opacity.
- Air-dried paper containing fines produced the strongest overall sheets because of the longer time available to form bonds.
- Force-dried (0% moist.) paper containing fines appeared to contribute the most to density and tensile index but only because fines-free values were lower and fines were more needed.
- Recycling decreased density and tensile index.
- Force-dried (0% moist.) paper containing fines contributed the least to wet-web strength and air-dried paper containing fines contributed the most to wet-web strength.
- Force-dried (0% moist.) paper containing fines gave pulps of highest CSF upon recycling and air-dried paper containing fines reduced CSF more extensively.
- WRV's decreased upon drying.
- Drying conditions did not give differences in response of fines on drainage.

CONCLUSIONS

The fines in paper subjected to air-drying conditions (or gentler drying conditions) contains fines which are the most active. They are the most active because they have the lowest scattering coefficient, the lowest CSF, and produce the strongest paper and strongest wet-web strength. These factors indicate that stronger bonding is occuring more so than when paper is force-dried.

The fines in the force-dried paper are less active and possibly immobilized, or attached to the longer fibers. This might explain the rise is freeness upon recycling and lower contribution to wet-web strength, yet still maintaining the largest contribution to density and tensile index of the recycled paper. As indicated by higher density increases, the fines are more needed after recycling and appear to be more effective, but not necessarily more active.

RECOMMENDATIONS

Future studies could examine the properties of fines at different freeness levels, for different species, different pulping methods, or include some refining of the recycled stock. By refining equally both the recycled stock with fines and the stock without fines, a more definite trend might appear as to the effect of drying on the fines.

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APPENDIX 1
Brightness (%)

0% Moisture	FD w/fines	75.87	OD wo/fines	80.68
6% Moisture	FD w/fines	74.64	OD wo/fines	82.20
6% Moisture	AD w/fines	72.80	AD wo/fines	81.29

APPENDIX 2
Opacity (%)

0% Moisture	FD w/fines	72.39	OD wo/fines	72.53
6% Moisture	FD w/fines	72.21	OD wo/fines	72.12
6% Moisture	AD w/fines	66.60	AD wo/fines	69.17

APPENDIX 3
Scattterering Coefficient

0% Moisture	FD w/fines	28.54	OD wo/fines	28.96
6% Moisture	FD w/fines	27.00	OD wo/fines	27.86
6% Moisture	AD w/fines	22.39	AD w/fines	24.54

APPENDIX 4
Absorption Coefficient

0% Moisture	FD w/fines	.35	FD wo/fines	.28
6% Moisture	FD w/fines	.45	FD wo/fines	.24
6% Moisture	AD w/fines	.37	AD wo/fines	.25

APPENDIX 5
Basis Weight (g/m2)

0% Moisture	FD w/fines	63.68	FD wo/fines	63.84
6% Moisture	FD w/fines	65.62	FD wo/fines	65.56
6% Moisture	AD w/fines	64.26	AD wo/fines	65.92

APPENDIX 6
Caliper (pts.)

0% Moisture	FD w/fines	4.705	FD wo/fines	5.205
6% Moisture	FD w/fines	5.100	FD wo/fines	5.185
6% Moisture	AD w/fines	4.909	AD wo/fines	5.150

APPENDIX 7
Density (g/cm3)

0% Moisture	FD w/fines	.5328	FD wo/fines	.4829
6% Moisture	FD w/fines	.5066	FD wo/fines	.4978
6% Moisture	AD w/fines	.5154	AD wo/fines	.5039

APPENDIX 8
Tensile Index (N m/g)

0% Moisture	FD w/fines	81.36	FD wo/fines	61.12
6% Moisture	FD w/fines	72.45	FD wo/fines	58.29
6% Moisture	AD w/fines	86.53	AD wo/fines	72.80

APPENDIX 9
Recycled Paper Brightness (%)

0% Moisture	FD w/fines	73.38	FD wo/fines	80.53
6% Moisture	FD w/fines	74.31	FD wo/fines	81.11
6% Moisture	AD w/fines	74.73	AD wo/fines	80,44

APPENDIX 10
Recycled Paper Opacity (%)

0% Moisture	FD w/fines	74.95	FD wo/fines	74.65
6% Moisture	FD w/fines	74.60	FD wo/fines	74.29
6% Moisture	AD w/fines	71.65	AD wo/fines	72.19

APPENDIX 11
Recycled Paper Scattering Coefficient

0% Moisture	FD w/fines	29.61	FD wo/fines	29.65
6% Moisture	FD w/fines	29.54	FD wo/fines	29.60
6% Moisture	AD w/fines	26.76	AD wo/fines	27.34

APPENDIX 12
Recycled Paper Absorption Coefficient

0% Moisture	FD w/fines	.46	FD wo/fines	.28
6% Moisture	FD w/fines	.42	FD wo/fines	.26
6% Moisture	AD w/fines	.40	AD wo/fines	.25

APPENDIX 13
Recycled Paper Basis Weight (g/m2)

0% Moisture	FD w/fines	66.94	FD wo/fines	68.03
6% Moisture	FD w/fines	67.78	FD wo/fines	67.34
6% Moisture	AD w/fines	65.23	AD wo/fines	66.80

APPENDIX 14
Recycled Paper Caliper (pts.)

0% Moisture	FD w/fines	5.78	FD wo/fines	6.30
6% Moisture	FD w/fines	5.72	FD wo/fines	6.15
6% Moisture	AD w/fines	5.59	AD wo/fines	6.05

APPENDIX 15

Recycled Paper Density (g/cm3)

0% Moisture	FD w/fines	.4560	FD wo/fines	.4251
6% Moisture	FD w/fines	.4665	FD wo/fines	.4311
6% Moisture	AD w/fines	.4594	AD wo/fines	.4347

APPENDIX 16

Recycled Paper Tensile Index (N m/g)

0% Moisture	FD w/fines	54.51	FD wo/fines	41.19
6% Moisture	FD w/fines	52.24	FD wo/fines	44.80
6% Moisture	AD w/fines	62.62	AD wo/fines	51.30

APPENDIX 17

Drainage (sec)

Never-dried	ND w/fines	7.32	ND wo/fines	4.33
0% Moisture	FD w/fines	7.84	FD wo/fines	4.72
6% Moisture	FD w/fines	7.90	FD wo/fines	4.63
6% Moisture	AD w/fines	8.05	AD wo/fines	4.73

APPENDIX 18

Canadian Standard Freeness (ml)

Never Dried	ND w/fines	384	ND wo/fines	662
0% Moisture	FD w/fines	481	FD wo/fines	648
6% Moisture	FD w/fines	475	FD wo/fines	649
6% Moisture	AD w/fines	450	AD wo/fines	643

APPENDIX 19

Wet-web Strength (g)

Never Dried	ND w/fines	427	ND wo/fines	336
0% Moisture	FD w/fines	241	FD wo/fines	229
6% Moisture	FD w/fines	255	FD wo/fines	224
6% Moisture	AD w/fines	280	AD wo/fines	221

APPENDIX 20

Water Retention Value

Never Dried	ND w/fines	3.14	ND wo/fines	2.90
0% Moisture	FD w/fines	2.68	FD wo/fines	2.30
6% Moisture	FD w/fines	2.67	FD wo/fines	2.42
6% Moisture	AD w/fines	2.61	AD wo/fines	2.36

APPENDIX 21

```
wet-tensile of unfractionated stock
NO.        X             Y


  1     6.9000E+00   1.0000E+01
  2     7.4000E+00   1.5000E+01
  3     7.4000E+00   1.4000E+01
  4     1.5900E+01   2.8900E+02
  5     1.7300E+01   3.2000E+02
  6     1.7400E+01   3.6100E+02
  7     1.8700E+01   3.8700E+02
DATA #=7cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

11-APR-93            OUTPUT            FOR 11-APR-93  DATA FROM
M                                     Wet-tensile of unfractionated stock




SLOPE = 3.2376320E+01
INTERCEPT = B =-2.2146358E+02
STANDARD ERROR OF ESTIMATE OF:
    Y-VALUES +- 1.2905264E+01
    SLOPE +- 9.6544808E-01
    INTERCEPT +- 1.3465343E+01

95% CONFIDENCE LIMITS IN:
    SLOPE = 3.2376320E+01 +-  2.4821670E+00
    INTERCEPT =-2.2146358E+02 +-  3.4619400E+01

                   CORRELATION COEFFICIENT =   9.9778455E-01
```

LINLSQ COMM **? APPENDIX 22
Wet-tensile of oven-dry unfractionated stock

NO.	X	Y
1	9.2000E+00	1.4000E+01
2	9.2000E+00	1.2000E+01
3	9.3000E+00	1.1000E+01
4	2.1000E+01	2.5900E+02
5	2.1100E+01	2.7200E+02
6	2.1300E+01	2.6200E+02

DATA *=?cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93 OUTPUT FOR 12-APR-93 DATA FROM
MBD Wet-tensile of oven-dry unfractionated stock

SLOPE = 2.1170839E+01
INTERCEPT = B =-1.8311057E+02
STANDARD ERROR OF ESTIMATE OF:
Y-VALUES +- 5.5692687E+00
SLOPE +- 3.8207713E-01
INTERCEPT +- 6.2308455E+00

95% CONFIDENCE LIMITS IN:
SLOPE = 2.1170839E+01 +- 1.0606461E+00
INTERCEPT =-1.8311057E+02 +- 1.7296827E+01

CORRELATION COEFFICIENT = 9.9934924E-01

```
LINLSQ COMM **?                    APPENDIX 23
Wet-tensile of 6% moisture-dry unfractionated    st
NO.        X              Y


  1     9.1ØØØE+ØØ  1.3ØØØE+Ø1
  2     9.1ØØØE+ØØ  1.4ØØØE+Ø1
  3     9.3ØØØE+ØØ  1.6ØØØE+Ø1
  4     2.Ø4ØØE+Ø1  2.57ØØE+Ø2
  5     2.Ø6ØØE+Ø1  2.6ØØØE+Ø2
  6     2.1ØØØE+Ø1  2.91ØØE+Ø2
DATA *=?cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93           OUTPUT          FOR 12-APR-93  DATA FROM
M6                                 Wet-tensile of 6% moisture-dry unfractionated
   st




SLOPE = 2.22Ø7834E+Ø1
INTERCEPT = B =-1.8943353E+Ø2
STANDARD ERROR OF ESTIMATE OF:
    Y-VALUES +- 8.7959461E+ØØ
    SLOPE +- 6.24174Ø6E-Ø1
    INTERCEPT +- 9.979Ø773E+ØØ

95% CONFIDENCE LIMITS IN:
    SLOPE = 2.22Ø7834E+Ø1 +-  1.7327Ø71E+ØØ
    INTERCEPT =-1.8943353E+Ø2 +-  2.77Ø192ØE+Ø1

                   CORRELATION COEFFICIENT =   9.984237ØE-Ø1
```

LINLSQ COMM **?type APPENDIX 24

Wet-tensile of air-dry unfractionated stock

NO	X	Y
1	8.1000E+00	1.4000E+01
2	9.0000E+00	2.1000E+01
3	9.1000E+00	1.7000E+01
4	2.0900E+01	2.9800E+02
5	2.1400E+01	3.0000E+02
6	2.2900E+01	3.6100E+02

DATA *=?cont

LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93 OUTPUT FOR 12-APR-93 DATA FROM

MAD Wet-tensile of air-dry unfractionated stock

SLOPE = 2.3300510E+01

INTERCEPT = B =-1.8644444E+02

STANDARD ERROR OF ESTIMATE OF:

Y-VALUES +- 1.1865394E+01

SLOPE +- 7.4119157E-01

INTERCEPT +- 1.2286056E+01

% CONFIDENCE LIMITS IN:

SLOPE = 2.3300510E+01 +- 2.0575478E+00

INTERCEPT =-1.8644444E+02 +- 3.4106091E+01

CORRELATION COEFFICIENT = 9.9798232E-01

APPENDIX 25

```
Fractionated Stock Wet Tensile
NO.          X               Y


  1     6.6200E+00   1.3000E+01
  2     7.0500E+00   1.2000E+01
  3     1.6310E+01   2.5300E+02
  4     1.7600E+01   2.7000E+02
  5     1.6560E+01   2.5200E+02
DATA *=?cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

 7-APR-93             OUTPUT            FOR  7-APR-93  DATA FROM
MIDDLE FRA                             Fractionated Stock Wet Tensile




SLOPE = 2.4590227E+01
INTERCEPT = B =-1.5573853E+02
STANDARD ERROR OF ESTIMATE OF:
    Y-VALUES +- 7.3137965E+00
    SLOPE +- 6.6763687E-01
    INTERCEPT +- 9.1752577E+00

95% CONFIDENCE LIMITS IN:
    SLOPE = 2.4590227E+01 +-  2.1244204E+00
    INTERCEPT =-1.5573853E+02 +-  2.9195669E+01

                    CORRELATION COEFFICIENT =   9.9889582E-01
```

APPENDIX 26

```
LINLSQ COMM **?
Wet-tensile of oven-dry fractionated stock
NO.          X                Y


   1      7.9000E+00   6.5000E+00
   2      8.5000E+00   1.2000E+01
   3      8.4000E+00   1.0000E+01
   4      1.9700E+01   2.2800E+02
   5      2.0500E+01   2.3600E+02
   6      2.1000E+01   2.4500E+02
DATA *=?cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93             OUTPUT           FOR 12-APR-93  DATA FROM
MSDF                                   Wet-tensile of oven-dry fractionated stock




SLOPE = 1.8662645E+01
INTERCEPT = B =-1.4458125E+02
STANDARD ERROR OF ESTIMATE OF:
    Y-VALUES +- 3.7421613E+00
    SLOPE +- 2.5121781E-01
    INTERCEPT +- 3.9114757E+00

95% CONFIDENCE LIMITS IN:
    SLOPE = 1.8662645E+01 +-  6.9738066E-01
    INTERCEPT =-1.4458125E+02 +-  1.0858256E+01

                   CORRELATION COEFFICIENT =   9.9963790E-01
```

```
LINLSQ COMM **?
Wet-tensile of 6% moisture-dry fractionated  stock
NO.          X                 Y
```

APPENDIX 27

```
   1      8.2000E+00  1.1000E+01
   2      8.5000E+00  1.0000E+01
   3      8.7000E+00  1.2000E+01
   4      2.0300E+01  2.2400E+02
   5      2.0800E+01  2.2900E+02
   6      2.0800E+01  2.5000E+02
DATA *=?cont
LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93            OUTPUT            FOR 12-APR-93  DATA FROM
M6F                                   Wet-tensile of 6% moisture-dry fractionated
stock


SLOPE = 1.8356089E+01
INTERCEPT = B =-1.4441440E+02
STANDARD ERROR OF ESTIMATE OF:
    Y-VALUES +- 8.4332952E+00
    SLOPE +- 5.6557924E-01
    INTERCEPT +- 8.9203568E+00

95% CONFIDENCE LIMITS IN:
    SLOPE = 1.8356089E+01 +-  1.5700480E+00
    INTERCEPT =-1.4441440E+02 +-  2.4762911E+01

                    CORRELATION COEFFICIENT =   9.9810666E-01
```

Wet-tensile of air-dry fractionated stock

NO.	X	Y
1	8.4000E+00	8.0000E+00
2	8.6000E+00	1.2000E+01
3	8.7000E+00	1.1200E+01
4	1.9300E+01	2.0800E+02
5	2.0600E+01	2.3400E+02
6	2.0800E+01	2.3400E+02

DATA #=?cont

LINEAR LEAST SQUARES STATISTICAL ANALYSIS

12-APR-93 OUTPUT FOR 12-APR-93 DATA FROM

MADF Wet-tensile of air-dry fractionated stock

SLOPE = 1.8426100E+01

INTERCEPT = B =-1.4750249E+02

STANDARD ERROR OF ESTIMATE OF:

Y-VALUES +- 1.7084788E+00

SLOPE +- 1.1916850E-01

INTERCEPT +- 1.8523579E+00

95% CONFIDENCE LIMITS IN:

SLOPE = 1.8426100E+01 +- 3.3081174E-01

INTERCEPT =-1.4750249E+02 +- 5.1421456E+00

CORRELATION COEFFICIENT = 9.9991626E-01